REMARKS

Enclosed herewith is a Substitute Specification in which the specification as filed has been amended in various places to correct typographical and grammatical errors, and also to add section headings. In addition, the specification as filed has been amended to cite U.S. Patent 4,790,014 corresponding to the cited European patent application. In support of the above, enclosed herewith is form PTO-1449 citing this U.S. patent.

In support of the above, enclosed herewith is a copy of the specification as filed marked up with the above changes.

The undersigned attorney asserts that no new matter has been incorporated into the Substitute Specification.

The claims have been amended to more clearly define the invention as disclosed in the written description. In particular, claim 5 has been made a proper dependent claim, depending from claim 1. In addition, the claims have been amended for clarity.

The Examiner has rejected claims 1-6 under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent 6,343,130 to Yamazaki in view of U.S. Patent 6,285,767 to Klayman.

The Yamazaki patent discloses a stereophonic sound processing system having a high-precision stereophonic filter means 21, a low-precision stereophonic filter means 22 and a switching unit 23 for selectively applying an input signal to one of said filter means 21 and 22, and for selecting the output from the

selected filter means 21 and 22. A CPU is coupled to the switching unit 23 for determining which of the filter means 21, 22 should be used. In a first embodiment (Fig. 13, col. 5, lines 50-67), the switching is done based on a user input. In a second embodiment (Fig. 14, col. 6, lines 1-22), the switching is done based on a performance measure of the CPU. In a third embodiment (Figs. 15-17 col. 6, line 23 to col. 7, line 19), the switching is done based on a monitoring of the CPU process. In a fourth embodiment (Fig. 18, col. 7, lines 20-40), the switching is done based on an amount of video processing also being performed. In a fifth embodiment (Fig. 19, col. 7, lines 41-67), the switching is done based on the localization of the sound signal as detected in the input signal. It should be noted that CPU does not compare the output signals from the filters to the input signal.

The Klayman patent discloses a low-frequency audio enhancement system "that enhances the perception of low-frequency sounds. In loudspeakers that do not reproduce certain low frequency sounds, the invention creates the illusion that the missing low-frequency sounds do exist. Thus, a listener perceives low frequencies, which are below the frequencies the loudspeaker can actually accurately reproduce" (col. 1, lines 56-61). In particular, as shown in Fig. 8 and described at col. 13, line 61 to col. 14, line 50, input left and right signals are combined (adder 806, amplified in amplifier 808 and applied to a low-pass filter

810 having a cut-off frequency of, for example, 200 Hz. An output from the low-pass filter 810 is provided to a plurality of band-pass filters 812-815 having pass-bands centered on, for example, 100 Hz, 150 Hz, 200 Hz and 250 Hz. The outputs from the band-pass filters are amplified in amplifiers 816-819, the outputs from which are then added and the resulting signal is added to the left and right input signals.

The subject invention concerns a bandwidth extension device which is capable of extending the bandwidth of an input audio signal. In particular, as claimed in claim 1, each of first and second signal paths have "filter means for filtering the input signal and creating means for creating an adapted signal with a lower frequency part than the input signal". As such, an output signal from the bandwidth extension device contains not only the bandwidth of the input signal, but also a lower frequency part than in the input signal. Further, the subject invention analyzes the first and second adapted signals from the first and second signal paths and compares these signals to the input signal, and then selects the most appropriate of the first and second adapted signals.

Applicants submit that neither Yamazaki nor Klayman disclose or suggest the bandwidth extension as claimed in claim 1. In particular, Yamazaki, as admitted by the Examiner does not specify creating the adapted signal with a lower frequency part

than the input signal. However, Klayman also does not create the adapted signal with a lower frequency part than the input signal. Rather, Klayman selectively amplifies the signal levels of selected frequency bands in the lower frequency range of the input signal. While, when listening to the resulting signal using a loudspeaker with poor low frequency performance, a listener is given the "impression" that frequencies below that of the capabilities of the loudspeaker are being heard, Applicant stress that Klayman neither discloses nor suggests that the results of the processing generates an adapted signal having a lower frequency part than the input signal.

Further, Applicants submit that neither Yamazaki nor Klayman disclose or suggest the analyze means of the subject invention "for comparing the first and second adapted signal with the input signal".

In view of the above, Applicants believe that the subject invention, as claimed, is not rendered obvious by the prior art, either individually or collectively, and as such, is patentable thereover.

Applicants believe that this application, containing claims 1-6, is now in condition for allowance and such action is respectfully requested.

Respectfully submitted,

by [signature]
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BACKGROUND OF THE INVENTION

Field Of The Invention

[0001] The invention relates to a bandwidth extension device comprising an input for receiving an input signal, filter means for filtering the input signal, creating means for creating an adapted signal with a lower frequency part than the input signal~~as defined in the preamble of claim 1~~.

[0002] The invention further relates to an audio reproduction system comprising such a bandwidth extension device.

Description Of The Related Art

[0003] Such a device is known from ~~the~~ European ~~patent~~ Patent ~~application~~ Application No. EP-A-0240286, corresponding to U.S. Patent 4,790,014. To improve the aural sensation in low-pitched (that is: signals in the very low frequency band) sound reproduction by an audio reproduction system or the like, a sub-harmonics generator is used to create this low-pitched signal. In this way, a lower pitch signal is created ~~then~~ than is present in the incoming signal.

[0004] A disadvantage of the known sub-harmonics generator and the known bandwidth extension device is that the amplitude of the sub-harmonics generator is not linear with the input voltage. Known

sub-harmonics generators usually clip the input signal and then divide the signal by two, for example, with a flip-flop, also, for example, a phase-locked loop is used to obtain the sub-harmonics.

SUMMARY OF THE INVENTION

[0005] It is an object of the invention to improve such a bandwidth extension device and to obtain such a bandwidth extension device, which is simpler. To this end a first aspect of the invention provides a bandwidth extension system as ~~defined in claim 1~~described above, characterized in that the bandwidth extension device comprises at least a first and a second signal path each having filter means and creating means for creating a first and a second adapted signal, analyze means for comparing the first and second adapted signal with the input signal, and summing and weighting means for selecting the adapted signal which corresponds most with the input signal~~.~~.

In this way, a bandwidth extension system is obtained which supplies a ~~low~~ low-pitched signal part with an amplitude proportional with the original signal.

[0006] Further, the created sub-harmonics have no discontinuities ~~instead of~~as opposed to the sub-harmonics of the prior art bandwidth extension device which have discontinuities.

~~Embodiments of the invention are described in the dependent claims.~~

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The invention and additional features, which may optionally be used to implement the invention to advantage, will be apparent from and elucidated with reference to the examples described below and hereinafter and shown in the figures~~. Herein shows~~, in which:

[0008] Fig. 1 shows an example of a bandwidth extension device according to the invention~~,~~;

[0009] Fig. 2 shows first diagrams of the harmonics streams of a signal in the frequency domain~~,~~;

[0010] Fig. 3 shows second diagrams of harmonics streams of a signal in the frequency domain~~,~~;

[0011] Fig. 4 shows a second example of a bandwidth extension device according to the invention~~,~~;

[0012] Fig. 5 shows a third example of a bandwidth extension device according to the invention~~,~~; and

[0013] Fig. 6 shows an example of an audio reproduction system according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] ~~Figure~~ Fig. 1 shows an example of a bandwidth extension device BD according to the invention. On an input I, the bandwidth extension device receives an input signal, for example, an audio signal. The input I is coupled to a first and a second band-pass

filter BPF11 ~~respectively~~ and BPF12, respectively. ~~From~~ These band-pass filter form ~~the (narrow-band) input signal~~ two band-limited parts ~~are taken~~from the (narrow-band) input signal, for example, one of 300-600 Hz (BPF11) and one of 300-450 Hz (BPF12).

[0015] The output of the band-pass filter BPF11 is coupled to a harmonics generator HG1 and the output of the band-pass filter BPF12 is coupled to a harmonics generator HG2.

[0016] The two harmonics generators HG1~~, resp.~~ and HG2 respectively produce two separate streams of harmonics of the selected frequency bands. Frequency components in the first band will be extracted as if the lowest harmonic in the narrow-band signal is the second ~~one~~harmonic, frequency components in the second band will be extracted as if the lowest harmonic in the narrow-band signal is the third ~~one~~harmonic, in this example.

[0017] The output of the harmonics generator HG1 is coupled to an input of switching means SM and the output of the harmonics generator HG2 is coupled to the other input of the switching means. The output of the switching means is coupled via a band-pass filter BPF2 to an output O of the bandwidth extension device BD.

[0018] It is not necessary that the filtering (BPF2) is equal for both branches, therefore instead of the band-pass filter BPF2 after the switching means, it is also possible to have two separate band-pass filters placed in both branches just before the switch means SM.

[0019] ~~To~~ Analyze means AM is used to decide which of the two harmonics streams in the frequency domain is the most appropriate one ~~analyze means AM are used~~. The analyze means ~~supply~~ supplies, as decision signal, a signal ss to the switching means SM. The analyze means receives the output signals from both harmonics generators ~~the output signals~~, and further the analyze means receives the input signal from the input I and make a decision on the basis hereof.

[0020] Of course, this decision is not valid for the whole excerpt, so this "best fit decision" should be made every so many samples. Two examples of harmonics streams in the frequency domain are given in ~~Figures~~ Figs. 2 and 3.

[0021] It appeared that it is not necessary to choose which of the harmonics generator gives the best results, when dealing with unvoiced speech. For ease in this example, unvoiced speech is treated the same as voiced speech.

[0022] To save computing time, ~~the~~ FFT can be used, which means that the number of samples within the input signal should be a power of 2.

[0023] A possible way to decide whether two signals contain similar information is to take their cross-correlation function.

Two signals with similar information are maximally correlated with each other.

[0024] The above can be used to select the harmonics stream in the frequency domain, which has the highest correlation with the narrow-band input signal. The harmonics stream consists of a fundamental and its higher harmonics. If the higher harmonics of the narrow-band signal are (roughly) the same as those of one of the harmonics streams, then that stream will most likely contain the right sub-harmonics too. This is in principle only valid for voiced speech.

[0025] ~~Figure~~ Fig. 2 shows an example of the harmonics streams in the frequency domain. A wide-band (1) signal is filtered to obtain a narrow-band signal (2). Of this signal, the first frequency component (3) is taken to generate two streams of harmonics, one as if this component was the second harmonic of the wide-band signal (4a) and one as if it ~~were~~ was the third (4b). Comparison of the plot (2) with plots (5a) and (5b) define which stream is most correlated and will most probably contain the right sub-harmonics (6a) and (6b). In this case (6b) fits best.

[0026] ~~For decision not t~~The whole spectra are used for this decision. All signals in consideration are, therefore, band-limited from 300 to 1200 Hz.

[0027] Since the energy of the harmonics streams is not equal, it ~~can~~ may be necessary to have some kind of normalization. This can be done by dividing both cross-correlation functions by the square root of the harmonics streams' auto-correlation function of ~~so~~ so-called lag zero.

[0028] All processing, such as filtering and generating harmonics, introduces delay and phase distortion. Hence, the cross-correlation function does not have to be symmetric around the origin. As a decision value, ~~we~~ use is made of the maximum of the cross-correlation function.

[0029] ~~Figure~~ Fig. 3 shows another example of the harmonics streams in the frequency domain. Also, in this example, the ~~wide~~ wide-band (1) signal is filtered to a narrow-band signal (2). Also here, of this signal, the first frequency component (3) is taken to generated two streams of harmonics, one as if this component was the second harmonic of the wide-band signal (4a) and one as if it ~~were~~ was the third (4b). In this example, stream 6a fits best.

[0030] ~~Figure~~ Fig. 4 shows a second example of a bandwidth extension system BD4. At the input I4, the bandwidth extension device receives an input signal, for example, an audio signal. This input I4 is coupled to n band-pass filters BPF411 …BPF41n. The band-pass filters have, in this example, the following frequency ranges:

BPF411: 300-400 Hz

BPF412: 350-450 Hz

....

BPF41n: ....

[0031] The output of each band-pass filter is coupled to an input of switching means SM4. The output of the switching means is coupled to the harmonics generator HG4. The output of the harmonics generator is coupled, via a band-pass filter BPF42, to the output O4 of the bandwidth extension device BD4.

[0032] The input I4 is also coupled to analyze means AM4 for analyzing the input signal and supplying a switching signal ss4 to the switching means SM4 and a control signal hs4 to the harmonics generator HG4.

In this way, it is possible to create more ~~choosing~~ opportunities for choosing the part of lower part of the frequency band for which the creation of sub-harmonics fits best by this input signal.

[0033] ~~Figure~~ Fig. 5 describes a third example of a bandwidth extension device BD5 according to the invention. At the input I5, the bandwidth extension device receives an signal. Also, in this example, two signal paths are available. The first one comprising a band-path filter BPF511 and a mixer MIX51 and a second path comprising a band-pass filter BPF512 and a mixer MIX512.

[0034] In this example, the analyze means AM5 also receives the input signal and the signals after the ~~band~~ band-pass filters. Here, the analyze means ~~supply~~ supplies a first control signal w1 and a second control signal w2. These control signals are supplied to the respective mixers MIX51 and MIX52. The outputs of the mixers are coupled to a summing device SUM5 for summing the two weighted signals and supplying, via the band-pass filter BPF52, the summed weighted signals to the output O5 of the band-width extension device BD5.

[0035] ~~Figure~~ Fig. 6 shows an example of an audio reproduction system AS6 comprising a band-width extension device BD6 according to the invention. The audio reproduction system further comprises ~~further~~ an input I6 for receiving an input signal. The input is coupled to a time delay device TD6 for compensating for the delay of the band—width extension device, the band-width extension device supplies, in this example, a control signal d6 to the time delay device. The output of the time delay device and the output of the band-width extension device are coupled to a summing device SUM6 for summing the (delayed) ~~origional~~ original signal and the band-width extended low frequency signal, at the output ASO6 of the audio reproduction system AS6.

[0036] It ~~will be noticed~~should be noted that above the invention has been described on the basis of some examples.

[0037] The man skilled in the art is well aware of alternatives within the scope of the invention.

[0038] For example, it is also possible to send information about the optimal filtering together with the signal to the "receiver". This is ~~clad~~ known in the art "non-blind" versus "blind" as described before. In that case, the analyze means only ~~have~~ has to decode the information about which filer is optimal for this signal and supply, for example, the control signals w1 and w2 (see ~~figure~~ Fig. 5) to the mixers.

[0038] Further, instead of using the time domain, the invention can also be used in the frequency domain using the inverse Fourier Transform (H H*9ejw)).

[0040] Above are examples described (see ~~figure~~ Figs. 2 and 3) with divide factors 2 and 3~~, of~~. Of course, also higher factors can be used.

ABSTRACT~~:~~ OF THE DISCLOSURE

To improve the aural sensation from an input signal of an audio reproduction system a bandwidth extension device can be used. ~~To improve the known bandwidth extension device the~~The bandwidth extension device ~~according to the invention~~ ~~comprises~~includes a first and a second signal path and ~~analyze means to select~~an analyzer for selecting the created signal~~,~~ which fits most for the current input signal.

~~Fig. 1~~